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TECHNICAL
PUBLICATION

PARABOLIC DISH MENSURATION TECHNIQUE

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NPIC/R-11/74
MARCH 1974

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INTRODUCTION

Communications systems and the ability to monitor them are of continuing interest to the intelligence community. The analyst needs to know the accurate diameter of an antenna so that it can be correctly classified by function and type. Further information can be determined when both the azimuth and inclination of the antenna are also known.

Equally important to the actual values for these antenna parameters of azimuth, inclination, and diameter are the confidence limits associated with these parameters. The analyst desires the most accurate determination that can be attained: the uncertainty associated with the measurement should be as small as possible. Thus the reported results should include both the parameters and the certainty with which they are known.

Most photogrammetric reductions are general purpose. They provide distances and azimuths between two identifiable points as well as cartesian or geodetic coordinates of individual points.

The basic problem is to determine inclination, azimuth, and diameter of a circle which lies on an inclined plane. To determine the inclination and azimuth, one must be able to identify certain critical points on the circle. This type of solution is subject to large errors because the critical points can be difficult to identify.

A solution has been derived for finding the inclination, azimuth, and diameter without having to measure the critical points directly. The solution is also independent of the photographic system. By using the method of least squares, the "best" estimates of the parameters and their associated accuracies are provided.

A technical discussion of the problem solution, program checkout, and comments about program operation are included in this report. The technical discussion involves a mathematical description, features of the program implementation, and an example of its application. The discussion on program checkout includes simulation as well as operational checks. Comments from practical experience conclude the report.

Technical Discussion

The mathematical description and the discussion of the computer program implementation are presented as separate topics in this section. The intent is to provide a basic outline rather than complete documentation.

Mathematical Description

The solution to the problem of determining dish antenna information begins by assuming the points of interest lie in a plane and fit a circle in three-dimensional space. Mathematically,

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these two conditions can be described by two equations. Let (X_i,Y_i,Z_i) represent the coordinates of point i measured in an arbitrarily positioned and oriented cartesian coordinate system. Let (X'_i,Y'_i,Z'_i) represent the coordinates of the same point referenced to a new (primed) cartesian coordinate system in which the X',Y' plane is in the plane of the circle and the Z' axis passes through the center of the circle. Then (X'_i,Y'_i,Z'_i) are related to (X_i,Y_i,Z_i) by three translations (X'_o,Y'_o,Z'_o) and a rotational matrix (M).

$$\begin{bmatrix} X'_i \\ Y'_i \\ Z'_i \end{bmatrix} = M \begin{bmatrix} X_i \\ Y_i \\ Z_i \end{bmatrix} + \begin{bmatrix} X'_o \\ Y'_o \\ Z'_o \end{bmatrix}$$

The plane and circle conditions can be written as

$$Z'_i = 0$$

$$(X'_i - X'_o)^2 + (Y'_i - Y'_o)^2 - R^2 = 0$$

where R is the radius of the circle. It is clear that two independent rotations suffice to angularly relate the two coordinate systems. Since the X_i,Y_i,Z_i are assumed to be in a topocentric coordinate system (Z up), the rotational matrix can be formulated as

$$M = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{SIN}\ I & \mathrm{COS}\ I \\ 0 & -\mathrm{COS}\ I & \mathrm{SIN}\ I \end{bmatrix} \begin{bmatrix} \mathrm{COS}\,\alpha & -\mathrm{SIN}\,\alpha & 0 \\ \mathrm{SIN}\,\alpha & \mathrm{COS}\,\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

where I is the inclination and α is the azimuth. See Figure 1.

In general the parameters X'_o,Y'_o,Z'_o, I,α, and R are unknown. With two equations per point, three points would be necessary for determining the six parameters. Typically it is possible to obtain more than three points with little additional work. It then becomes convenient to use a least squares algorithm for parameter determination. The problem is nonlinear in both the parameters and the observations. The general solution to such a problem is given by Brown (1955).[1] In special situations the radius of the circle may have been attained previously along with its associated variance. In this case the parameter R becomes an observation. The solution to the problem under this condition is given by Schmid and Schmid (1965).[2]

One distinct advantage of the least squares algorithm is that a byproduct of the computations is a convariance matrix for the computed parameters. Thus appropriate confidence bounds may be formed.

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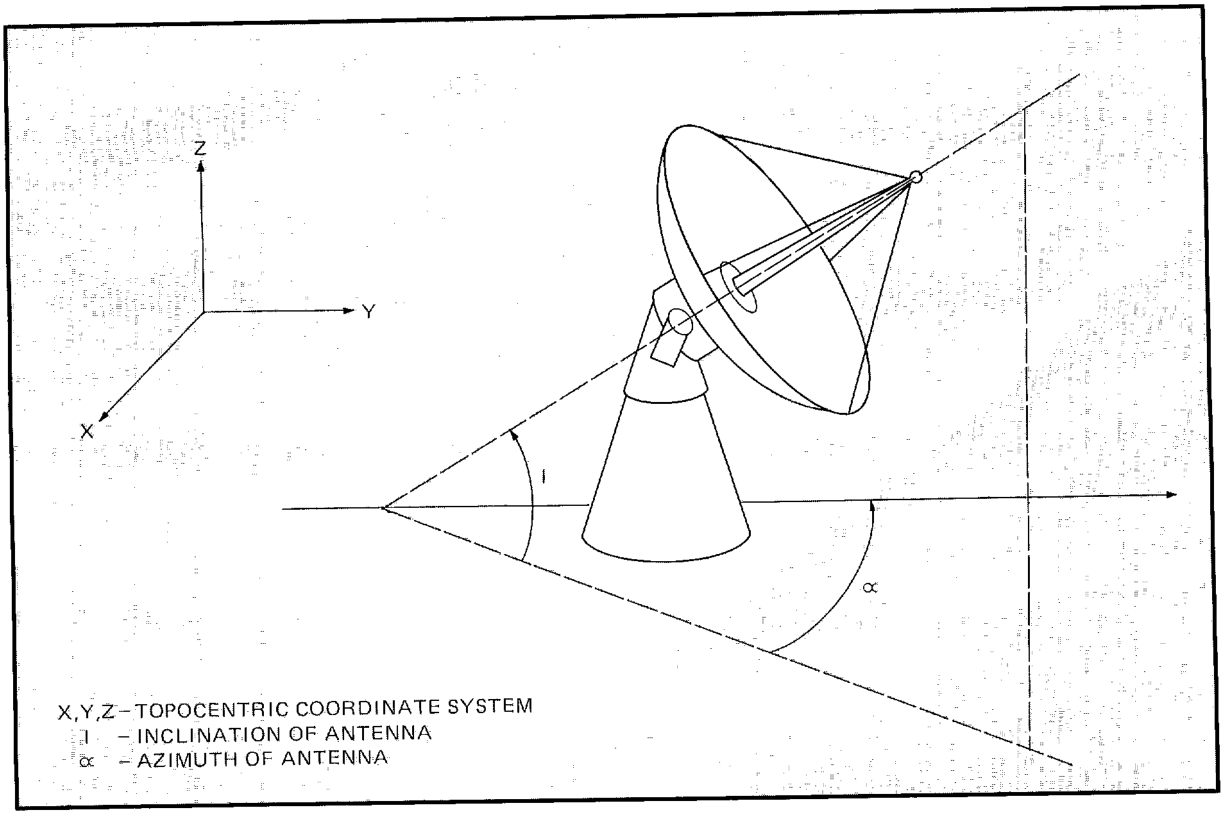

FIGURE 1. ROTATION PARAMETERS AND COORDINATES

FORTRAN Program Implementation

There are a number of features of the FORTRAN program implementation that make the program particularly useful. One feature is the use of free-form input. This concept allows the user to punch the data cards any way he chooses as long as the data is arranged in the correct order.

Another feature is the internal computation for the initial approximations. Because the problem is nonlinear, an iterative solution is used. Initial approximations are important for minimizing computational time and arriving at the correct minimum.

A third feature is an automatic data editing scheme. The theory behind the scheme is that it is better to reject a potentially bad observation than to include it. Thus, after a first adjustment the contribution of each point to the sum of square of the residuals is examined to determine the "worst" point. Since it may be known apriori that some points are worse than others, each point is given a weight as defined by the user. Then the point contribution to the weighted sum of the residuals squared is evaluated. The rejection criterion is based on an F test between the largest contribution and the total sum of squares (including the bad point). The

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user controls the level of rejection by specifying the probability of rejecting a good value (α -level). If a point is edited, a new adjustment is computed. The process is repeated until no points are deleted.

Finally, there are two features of the output that are worth mentioning. First, a 95% confidence interval (C.I.) for the computed diameter is given. This C.I. is computed from the marginal variance given by the covariance matrix of the parameters. Also a joint 95% confidence region for the inclination and the azimuth are given. This is formed by partitioning the covariance matrix of the parameters and using the appropriate F value. The other output feature is a two-dimensional plot of the data points in the plane of the fitted circle. If the adjustment fails to converge to a solution, then the initial approximations are used to generate the plot.

Program Input Data

The program is set into operation by furnishing the following:

A. Parameters

1) A mode indicator that determines if the solution is to be run with R as an observation or an unknown parameter

2) The azimuth of the +Y axis of the topocentric cartesian coordinate system

3) The alpha value that is used to control the level of the rejection of suspect points

4) The total number of data points that are input

B. Data Points

1) An identification number

2) The apriori weight, as assigned by the user

3) The X_i, Y_i, Z_i topocentric coordinates of point i

Example of Program Output

Figures 2 and 3 provide an example of the output for the mensuration of a parabolic dish antenna. The results of the functions that were performed by the program are shown in Figure 2. The following is a brief description for each element of the output.

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A. The first line contains the input values for the azimuth of the +Y axis, alpha level, and the number of points.

B. The weighting vector gives the value of the input weights for each of the data points.

C. Initial approximations are the initial values for the parameters to be used in the adjustment.

D. The parameters resulting from each adjustment are shown under the heading Adjustment Results.

E. S02 is the variance of unit weight as calculated by the adjustment.

F. The number of iterations needed for convergence is also shown. The maximum number is 20.

G. Editing vector shows the weight of all the points and edited points (shown by weight becoming zero).

H. The input X, Y, and Z local coordinates are listed as Data Points with the associated corrections (VX,VY,VZ) that were applied to obtain the final adjusted values.

I. The worst point still in the solution and the alpha level necessary to reject that point is also given.

J. The last line shows the final adjusted values for azimuth, inclination, and diameter with the 95% confidence interval or bound for each.

Figure 3 is a plot with the adjusted position for all the data points including any deleted points. When two points are close together, the numerical identifier for one of the points will not be shown. The best fit circle is also plotted so that it is easier to see the relative positions of the adjusted points.

Program Validation

The program has been tested through simulations as well as operational checks. A random normal deviate generator was used to modify fictitious data to check the program. Different combinations of the azimuth, inclination, diameter, and number of points were run through the program.

In no case were any points deleted from the solution. No inclinations or azimuths differed from the known value by more than the confidence bounds. One diameter of 17 differed from the known value by more than the derived confidence interval.

An area having parabolic dish antennae with known parameters was used to check the program operationally. The computed parameters plus each confidence interval always contained the known ground values.

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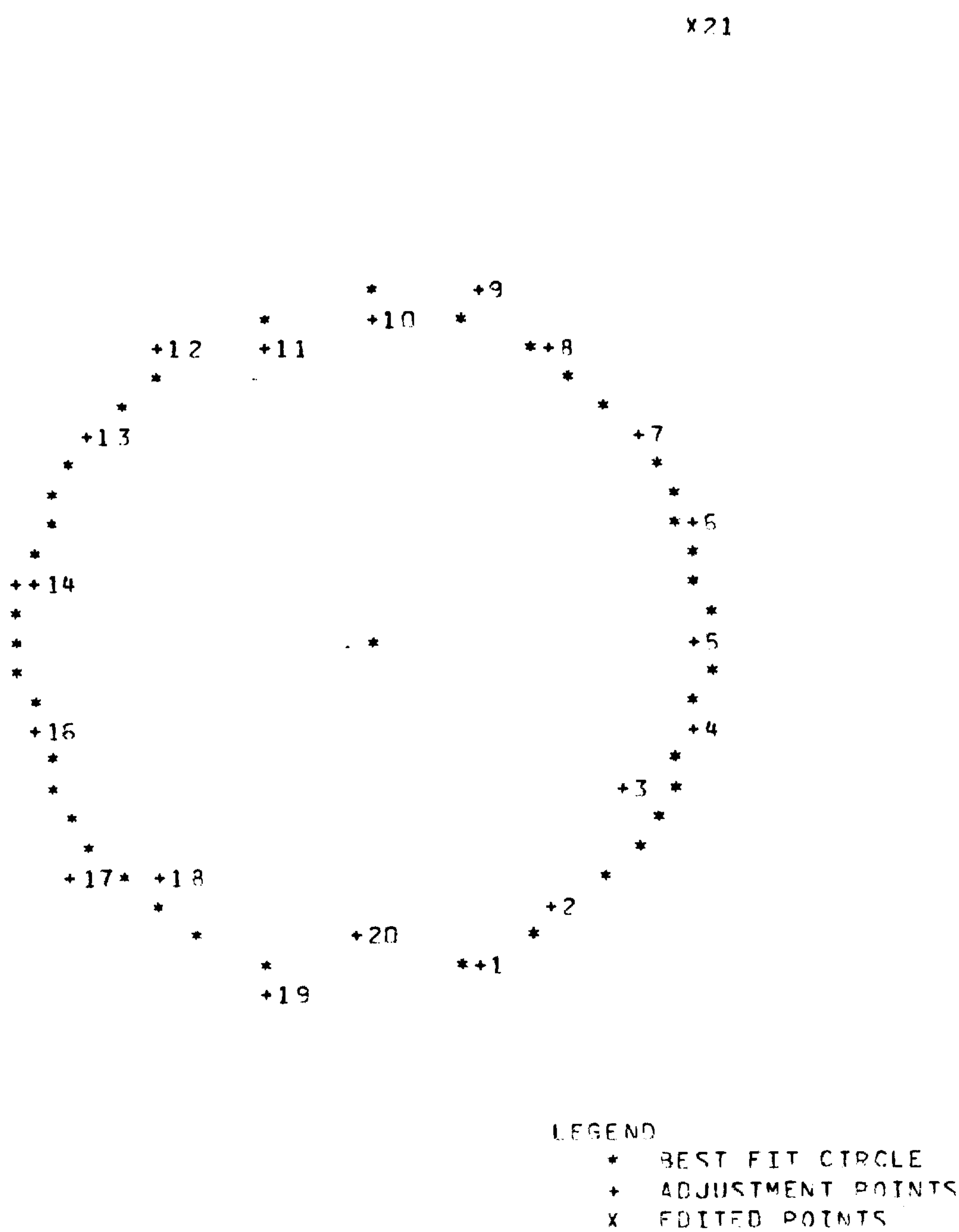

FIGURE 3. EXAMPLE OF PLOT

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Comments on Practical Application

The program has been in operational use for over one year. In this period the program has been used in all cases when both azimuth and inclination were required.

The program has proven to be beneficial by --

a) making the input cards easy to prepare because of the free form concept.

b) reducing computer time and frequency of runs.

c) allowing measurement of antennae that previously could not be measured because critical points could not be determined.

d) automatically editing points that previously had to be removed by inspection.

e) calculating a statistically significant confidence interval.

f) giving a visual record of the data points even if the adjustment does not converge.

g) determining more accurate values than any previous method available.

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